CEvNS Overview

Sonia Bacca

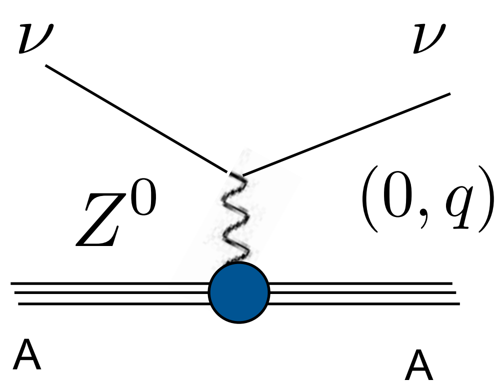
Johannes Gutenberg Universität Mainz

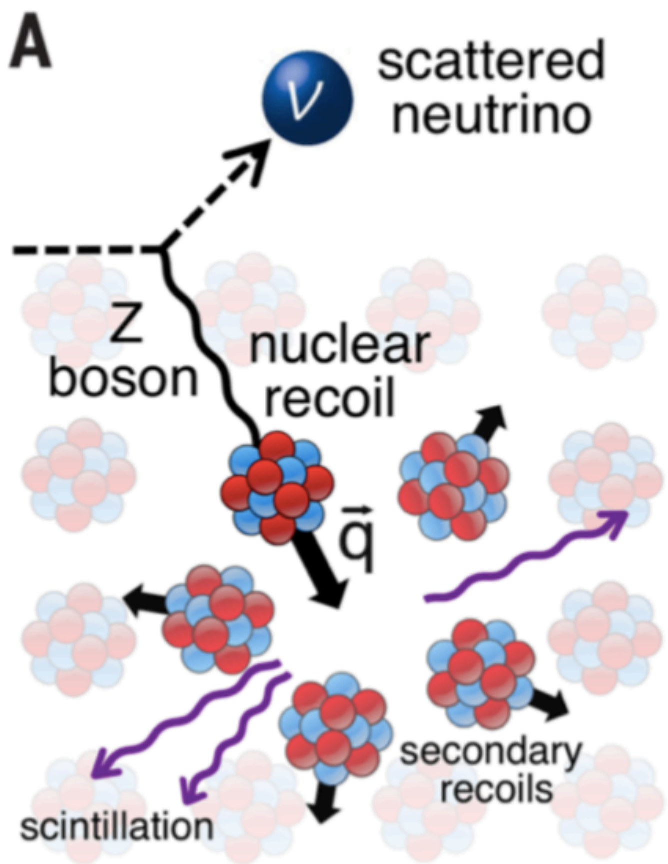
November 12, 2021

Low-energy Neutrino and Electron Scattering Workshop

Coherent elastic neutrino-nucleus scattering

CEvNS



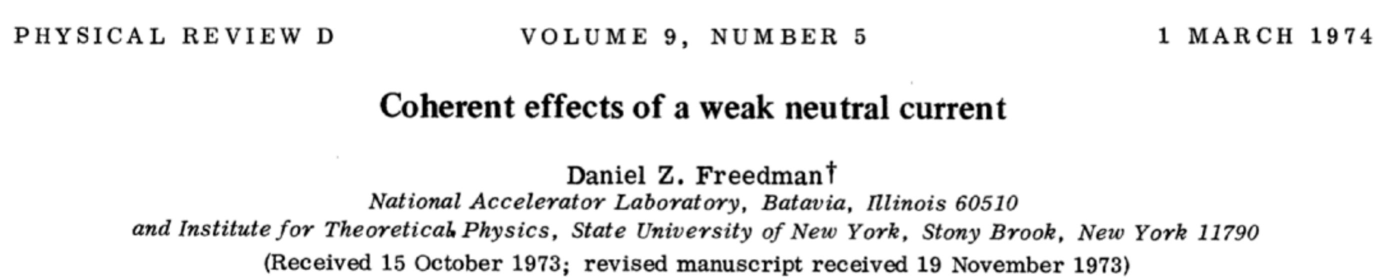


The neutrino exchanges a Z-boson with the nucleus, that recoils as a whole (no internal excitation).

Coherent up to neutrino energies of 50 MeV

Signature: tiny energy deposited by nuclear recoils in the target material.

First proposed by Freedman in 1974


PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

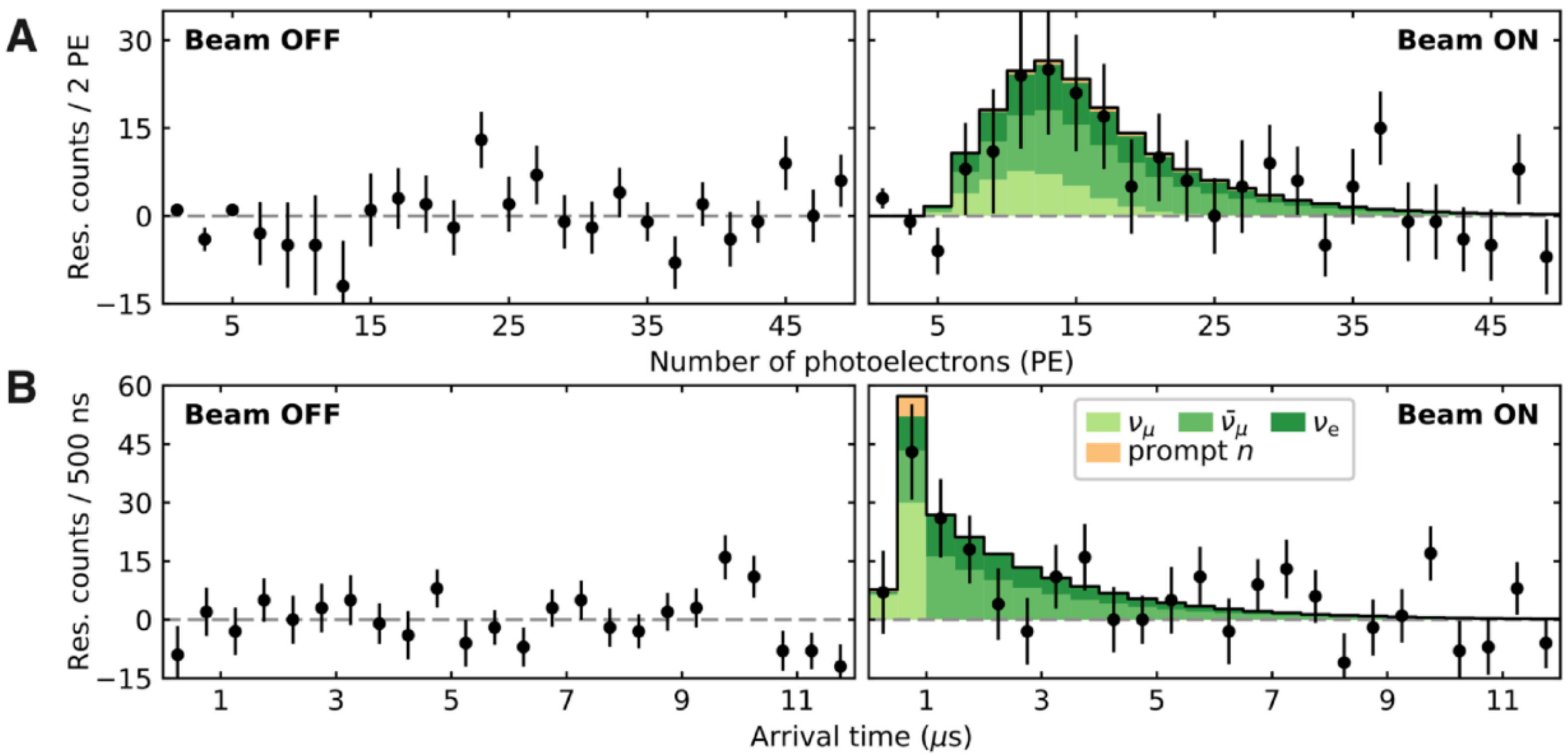
Coherent elastic neutrino-nucleus scattering

First observed in 2017

Science REPORTS

Cite as: D. Akimov *et al.*, *Science* 10.1126/science.aao0990 (2017).

Observation of coherent elastic neutrino-nucleus scattering



CEvNS worldwide

Courtesy of K. Scholberg

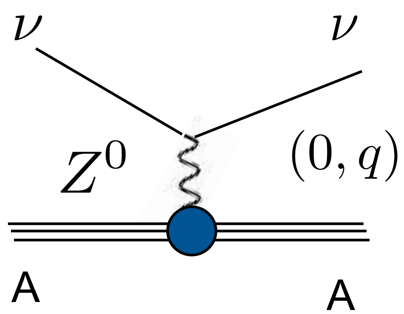
Experiment	Technology	Location	Source
COHERENT	CsI, Ar, Ge, NaI	USA	πDAR
CCM	Ar	USA	πDAR
CONNIE	Si CCDs	Brazil	Reactor
CONUS	HPGe	Germany	Reactor
MINER	Ge/Si cryogenic	USA	Reactor
NuCleus	Cryogenic $CaWO_4$, Al_2O_3 calorimeter array	Europe	Reactor
νGEN	Ge PPC	Russia	Reactor
RED-100	LXe dual phase	Russia	Reactor
Ricochet	Ge, Zn bolometers	France	Reactor
TEXONO	p-PCGe	Taiwan	Reactors

Why is it important?

- Signal for new neutrino physics
- Probe for nuclear physics
- Background for signature of new physics
- …

CEvNS from the standard model

$$\frac{d\sigma}{dT}(E_\nu, T) \simeq \frac{G_F^2}{4\pi} M \left[1 - \frac{MT}{2E_\nu^2}\right] Q_W^2 F_W^2(q^2)$$



Weak charge

$$Q_W = N - (1 - 4\sin^2\theta_W) Z$$

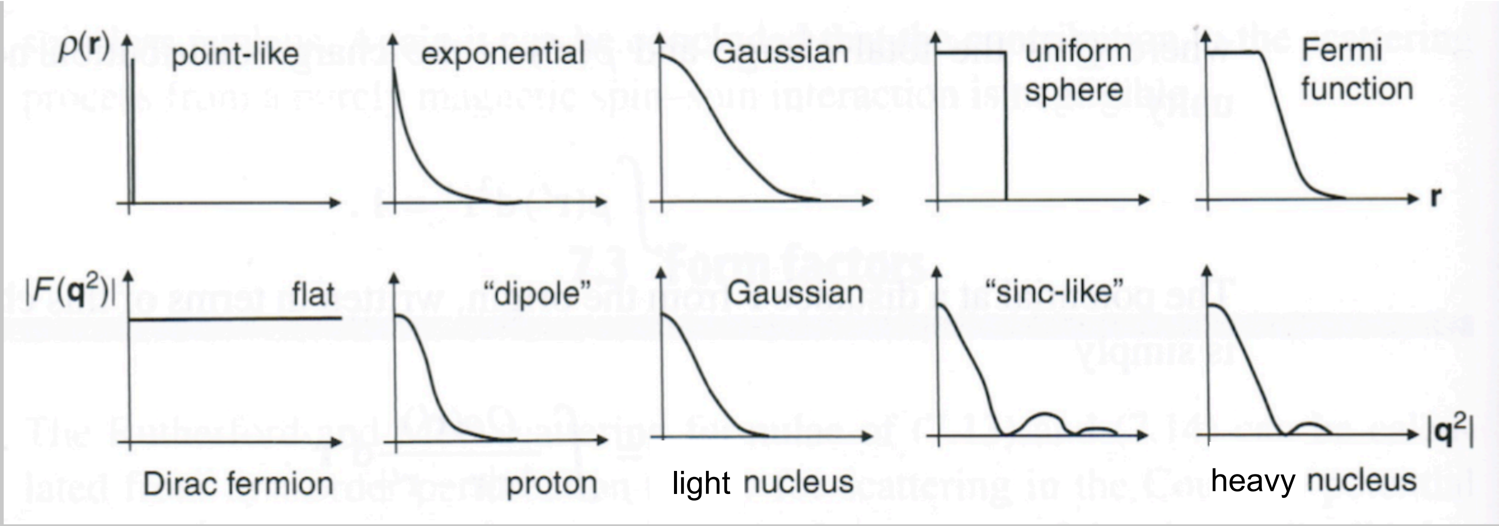
	Proton	Neutron
Electric charge	1	0
Weak charge	~0.08	~-1

Weak form factor

$$\boxed{F_W(q^2)} = \frac{1}{Q_W}\left[N F_n(q^2) - \cancel{(1 - 4\sin^2\theta_W) Z F_p(q^2)}\right]$$

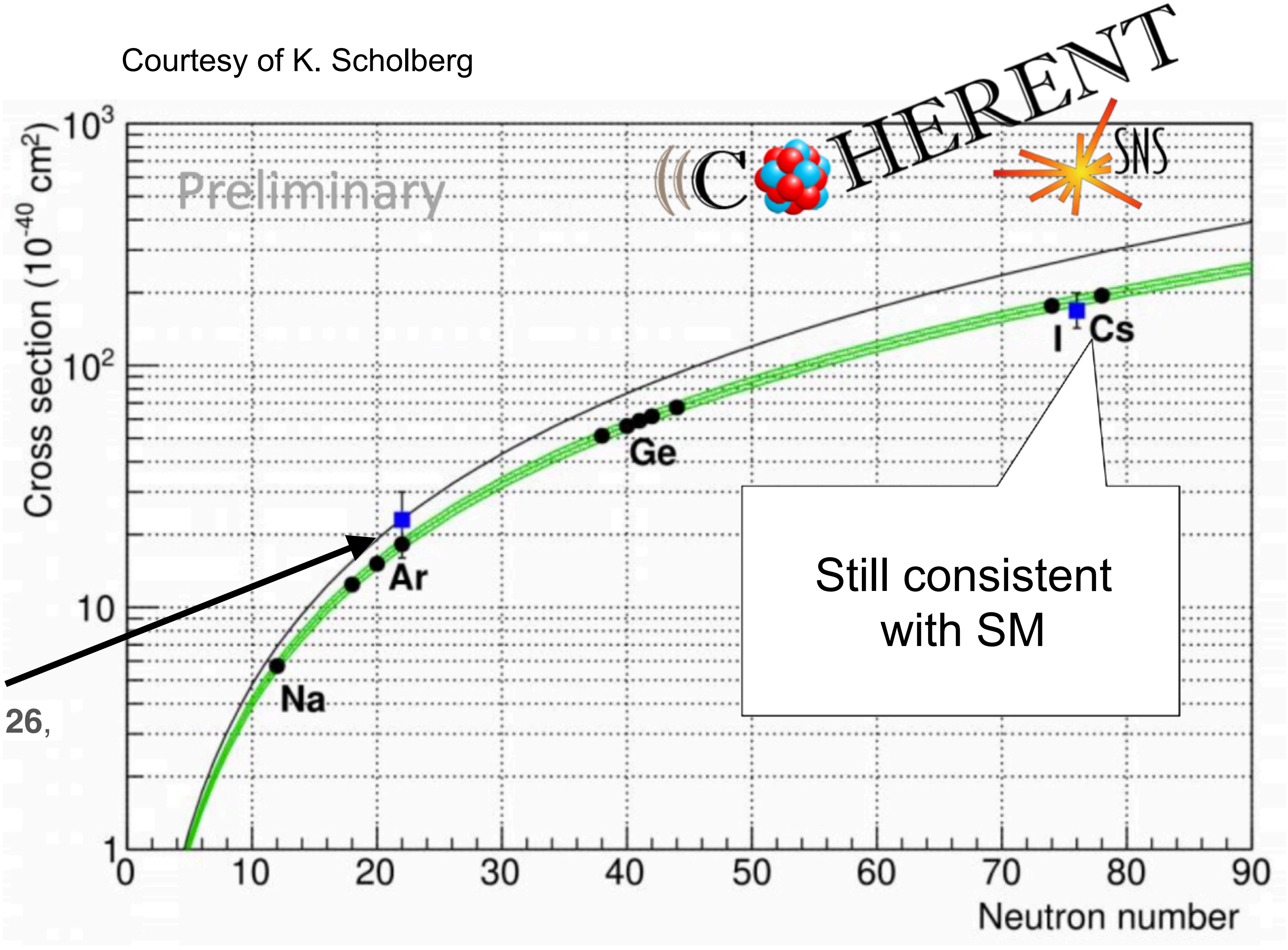
Sensitive to neutron distribution

$$F(q^2) = \int d\mathbf{r}\; e^{i\mathbf{q}\cdot\mathbf{r}} \rho(\mathbf{r})$$



CEvNS from the standard model

Courtesy of K. Scholberg



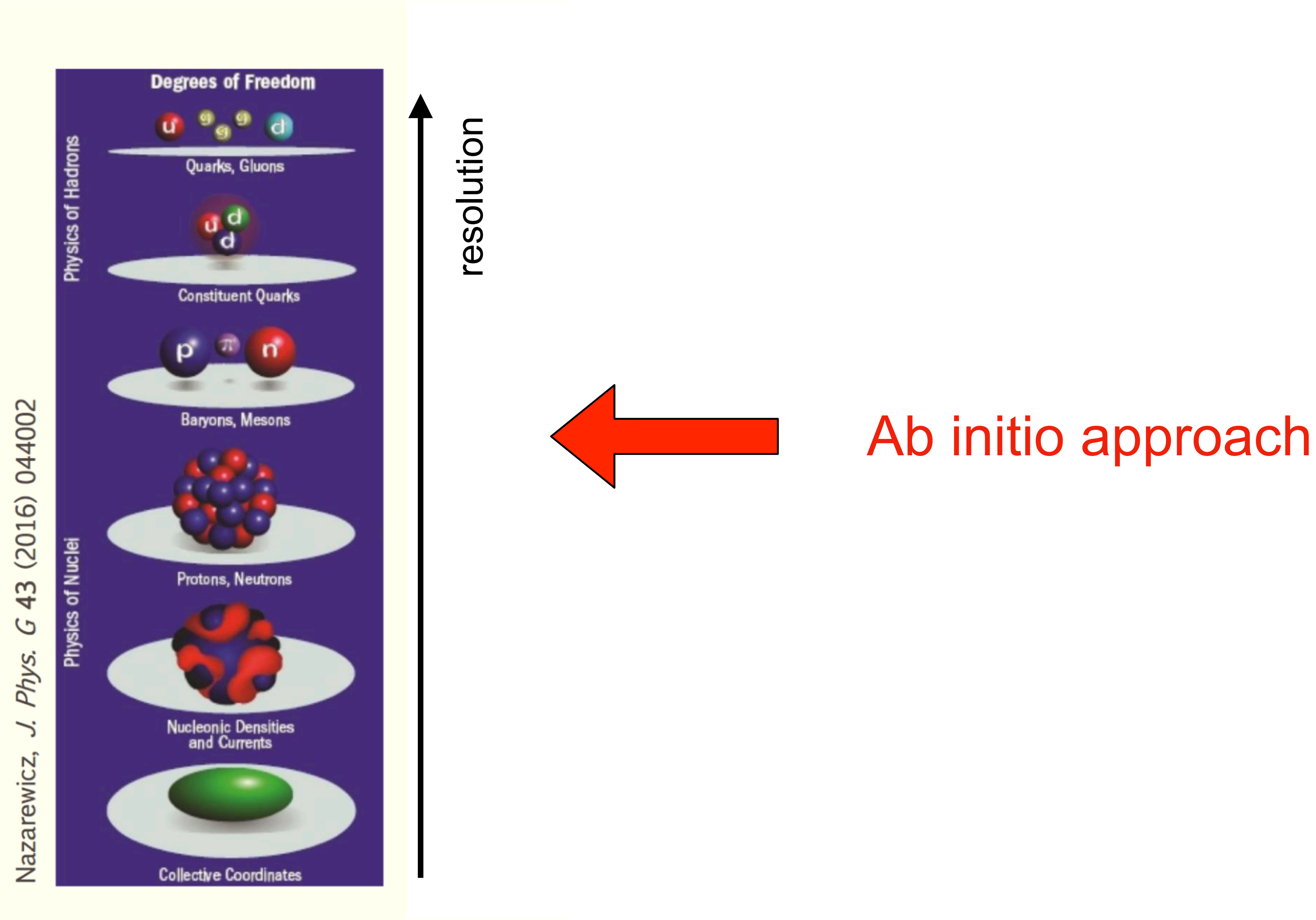
Phys. Rev. Lett. **126**, 012002 (2021)

Measuring CEvNS precisely, deviations from the SM expectation will inform about new physics.

Since nuclear physics is at play we need to quantify and control nuclear structure effects.

Nuclear structure theory

Probing the nucleus at different resolutions

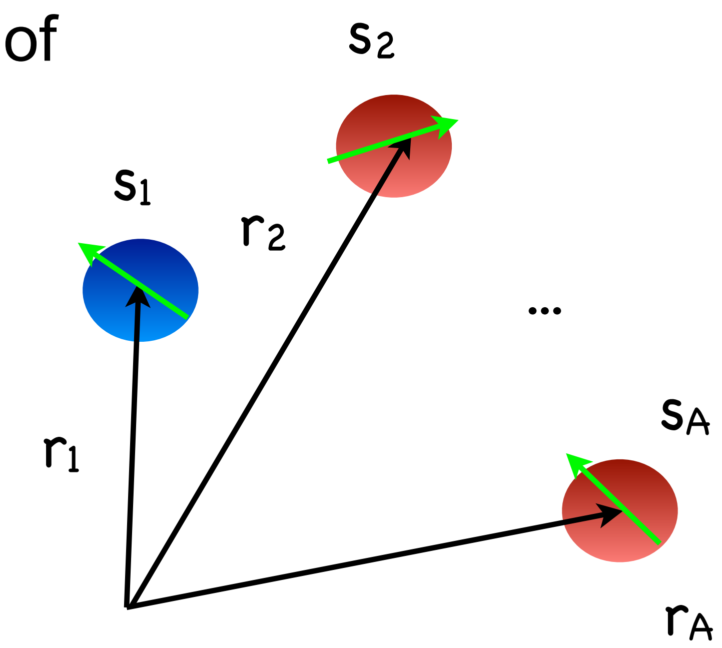


Nuclear structure theory

Ab initio approach

- Start from neutrons and protons as building blocks (centre of mass coordinates, spins, isospins)

- Solve the (non-relativistic) quantum mechanical problem of A-interacting nucleons



$$H|\psi\rangle = E|\psi\rangle$$

$$H = T + V_{NN}(\Lambda) + V_{3N}(\Lambda) + \ldots$$

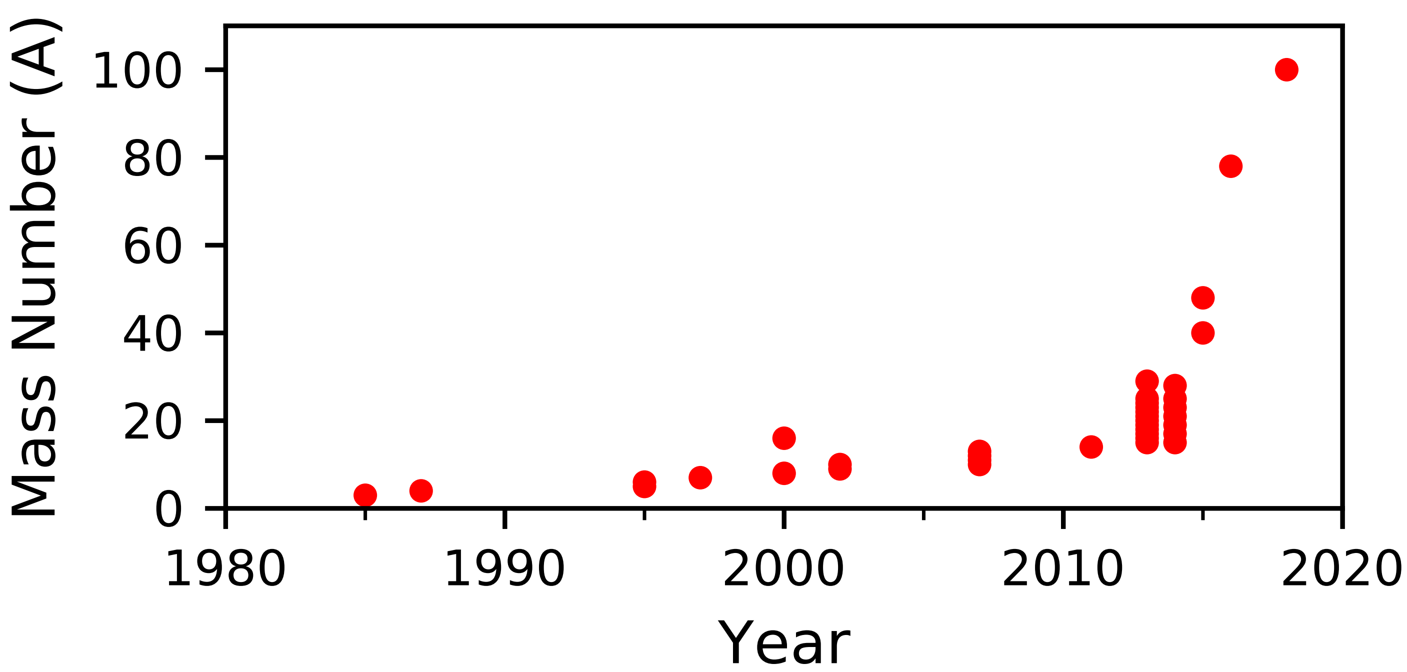
chiral effective field theory

- Find numerical solutions with no approximations or controllable approximations

Nuclear structure theory

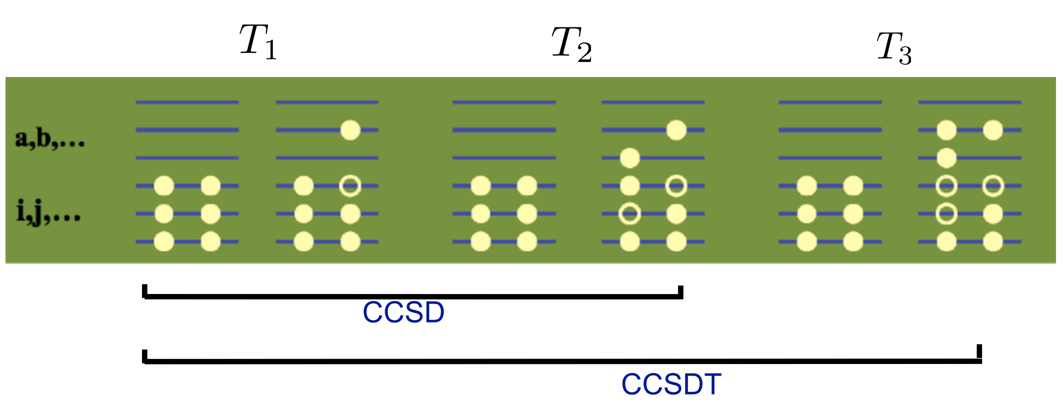
Coupled-cluster theory ⟶ Many-body solver

In collaboration with ORNL group



$$|\psi_0(\vec{r}_1, \vec{r}_2, ..., \vec{r}_A)\rangle = e^T |\phi_0(\vec{r}_1, \vec{r}_2, ..., \vec{r}_A)\rangle$$

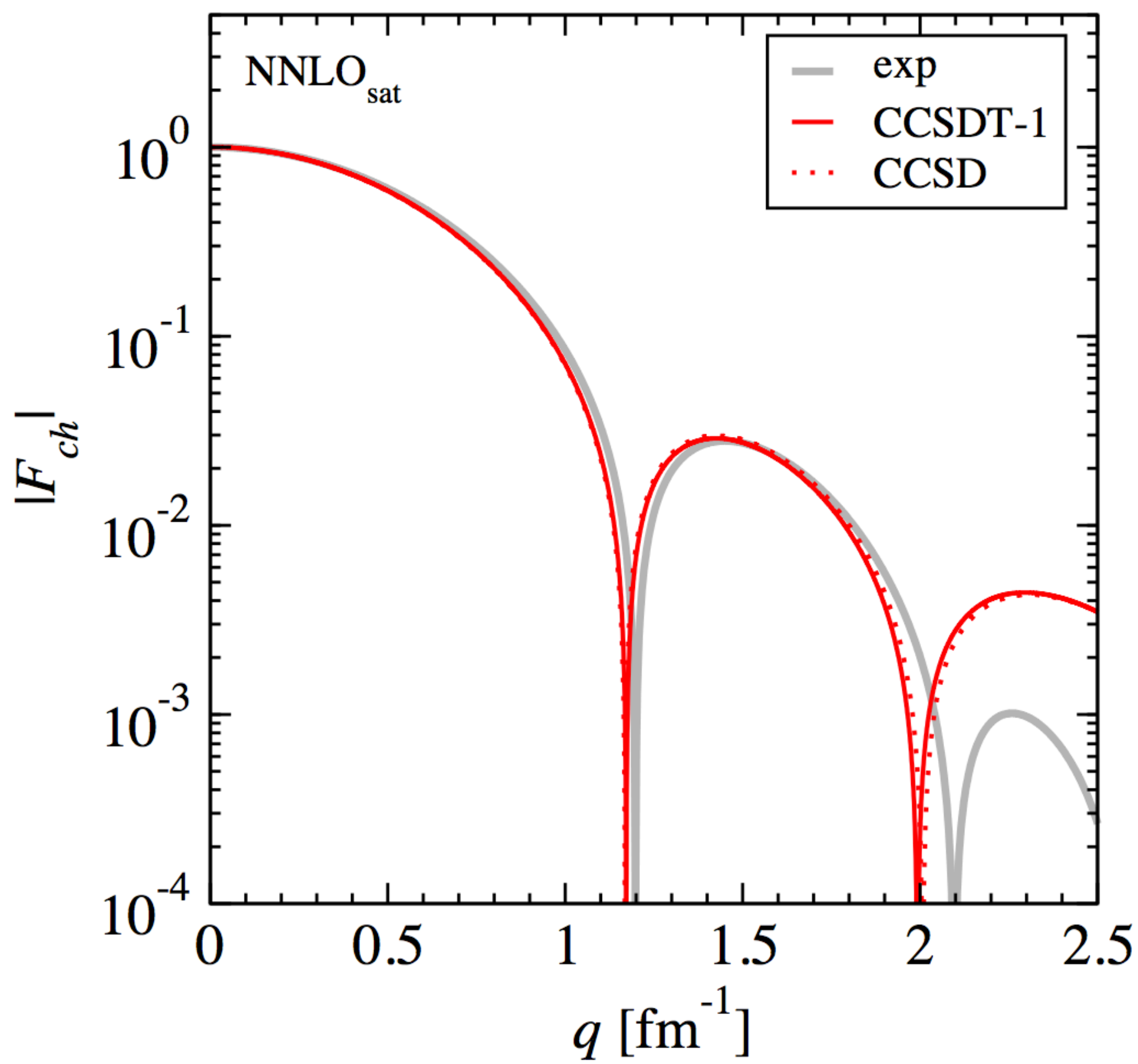
$T = \sum T_{(A)}$ cluster expansion



Very efficient: polynomial scaling

^{40}Ar Charge Form Factor

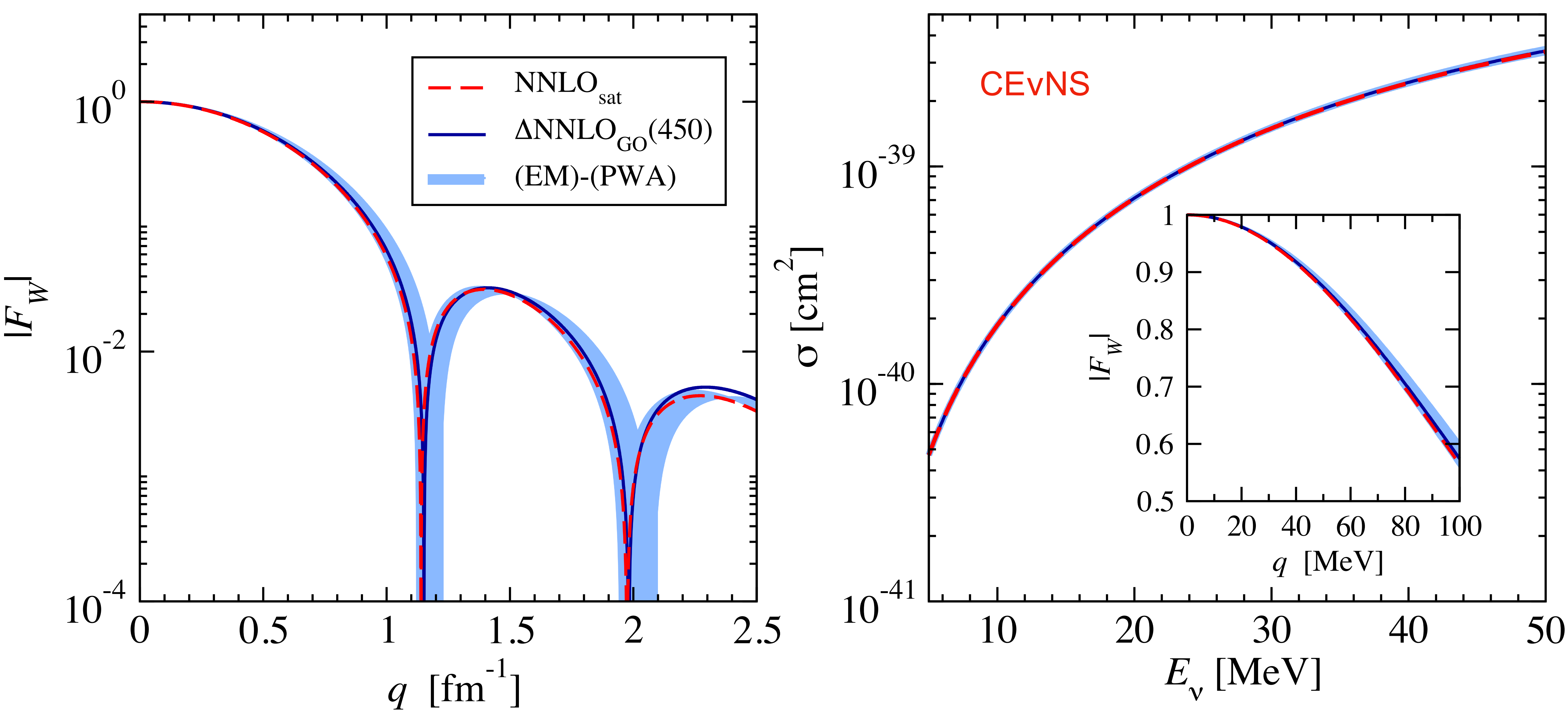
C. Payne, S.B. et al., Phys. Rev. C 100, 061304(R) (2019)



exp: in Mainz, Ottermann et. al., Nucl. Phys. A **379**, 396 (1982)

^{40}Ar Weak Form Factor

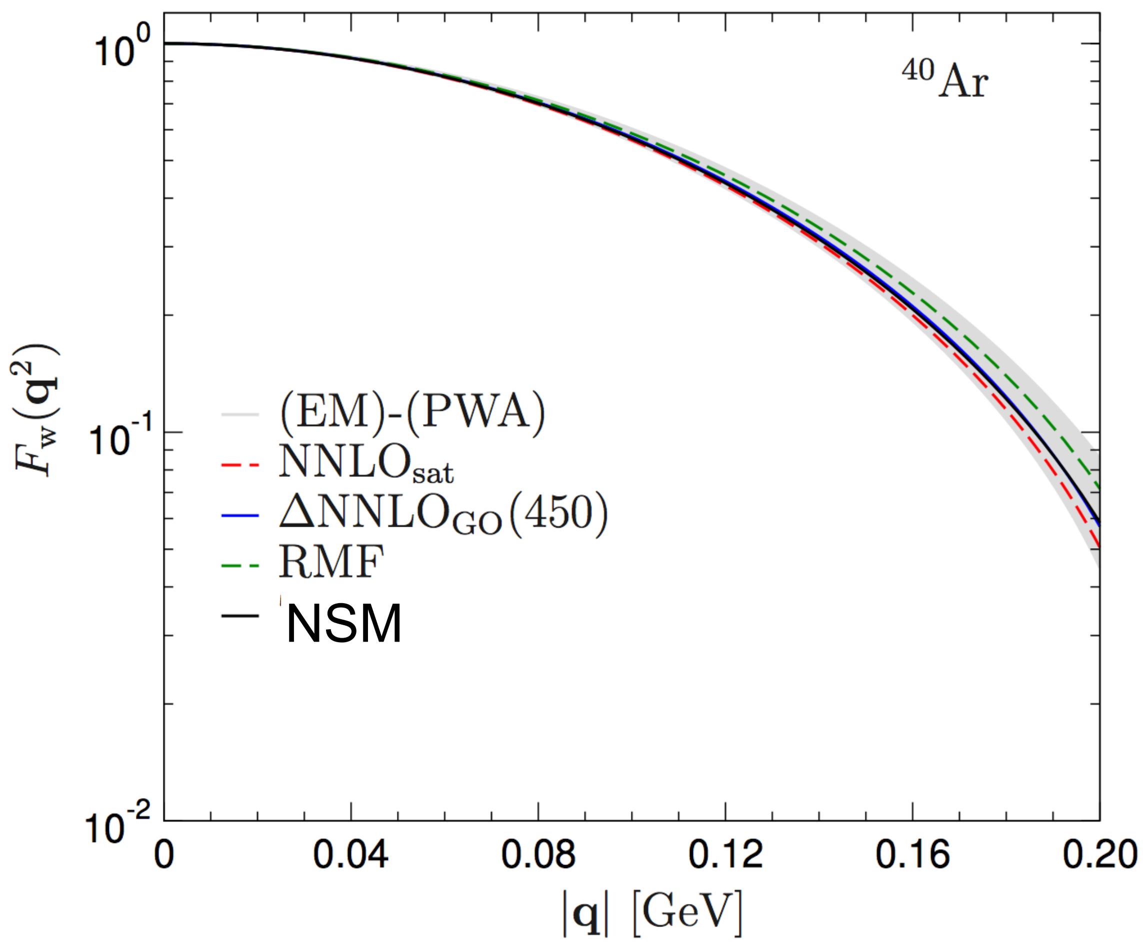
C. Payne et al., Phys. Rev. C 100, 061304(R) (2019)



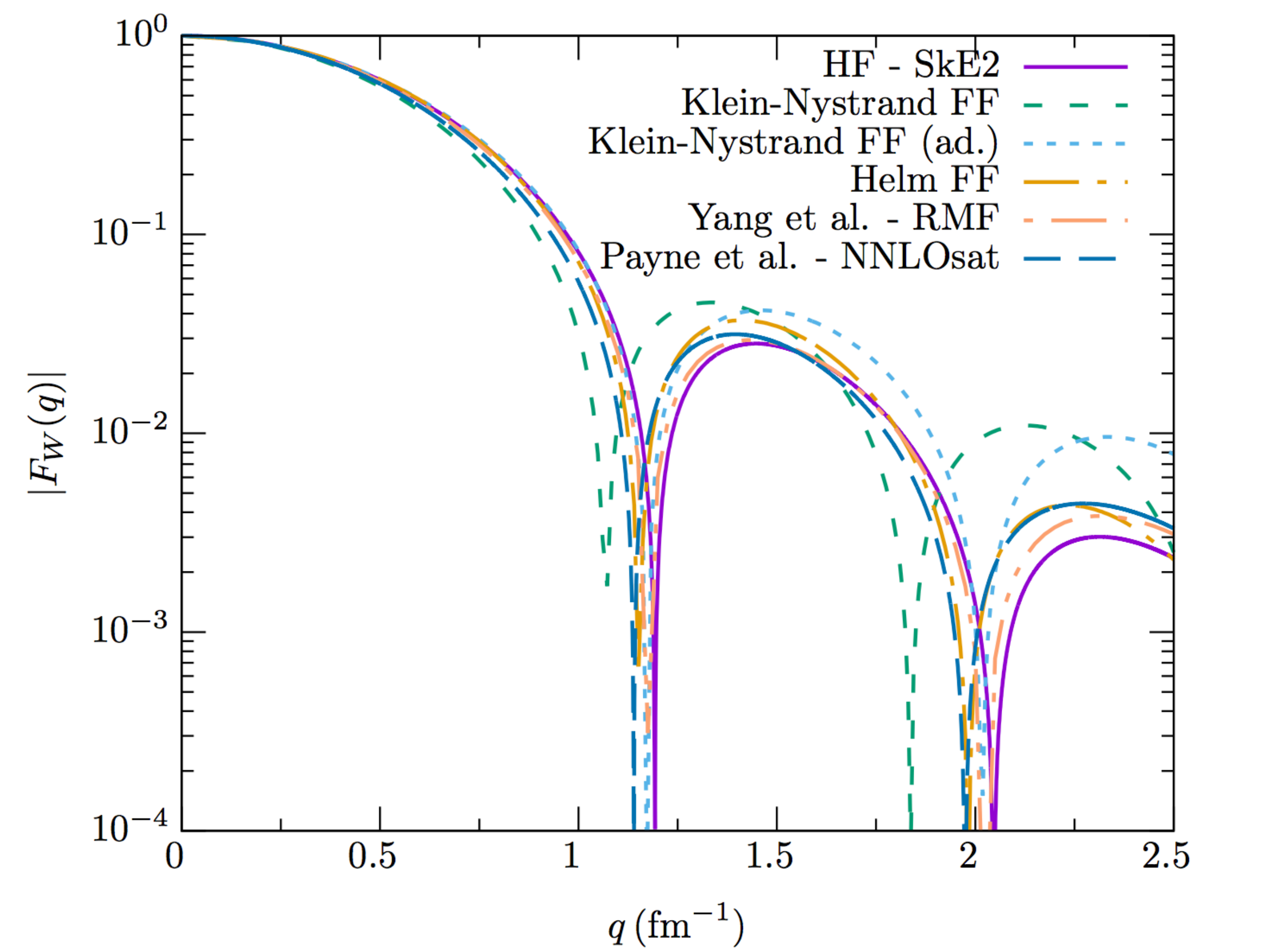
Small nuclear structure uncertainty in the cross section: 2% at q=50 MeV, as opposed to 40% estimated in Sierra et al., arXiv:1902.07398v1, later corrected to 5%, JHEP 1906:141 (2019).

Comparison to other calculations

Hoferichter et al., PRD **102**, 074018 (2020)



Van Dessel et al., **arXiv:2007.03658**



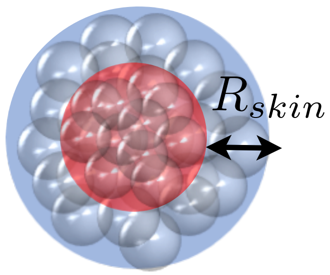
See also RMF Yang et al., Phys. Rev. C 100, 054301 (2019)
and HF+BCS calculations in Co' et al., JCAP04(2020)044, arXiv:2001.04684.

Confirm small nuclear structure uncertainties, which is good news for BSM searches.

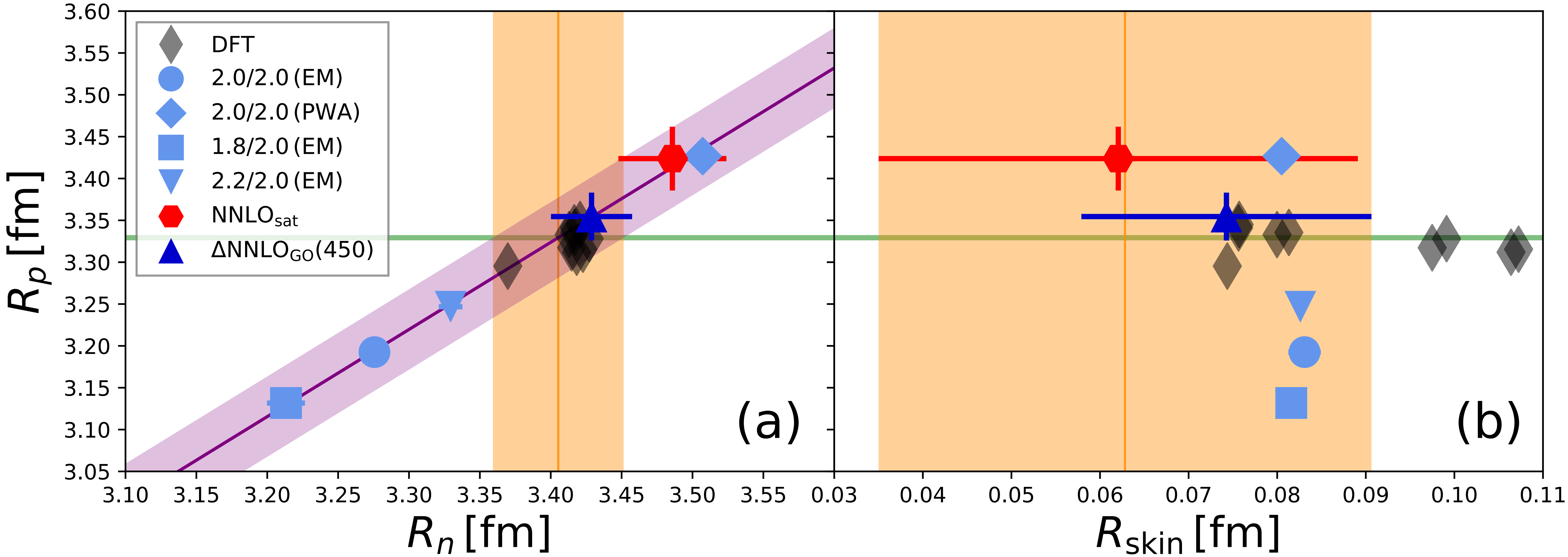
^{40}Ar neutron skin-thickness

C. Payne et al., Phys. Rev. C 100, 061304(R) (2019)

Perhaps R_n and R_{skin} can be extracted from coherent elastic neutrino scattering



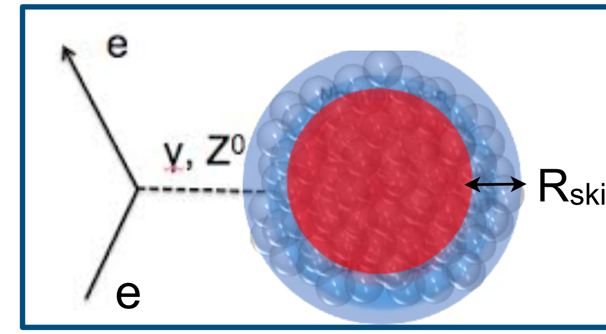
Amanik and McLaughlin, J. Phys. G: Nucl. Part. Phys. **36** 015105 (2009)
Cadeddu et al., Phys. Rev. Lett. **120**, 072501 (2018)



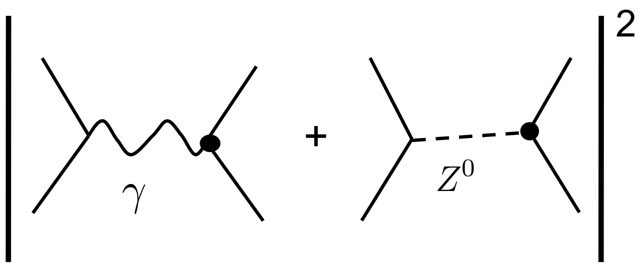
DFT from N. Schunck, private communication, **HFB9, SKI3, SKM*, SKO, SKX, SLY4, SLY5, UNEDF0, UNEDF1**

Parity violating electron scattering

polarized beam



unpolarized target

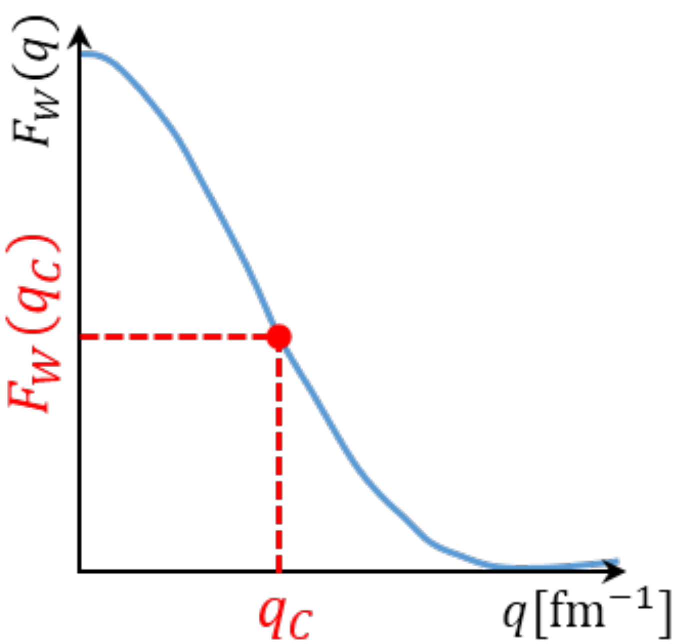


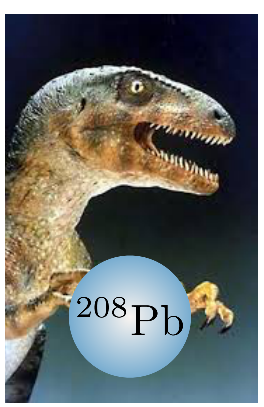
$$= |M_\gamma + M_{Z^0}|^2 \sim |M_\gamma|^2 + 2M_\gamma(M^*_{Z^0}) + \ldots$$

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \approx -\frac{G_F q^2}{4\pi\alpha\sqrt{2}} \frac{Q_W F_W(q^2)}{Z F_{ch}(q^2)}$$

Measure F_W to infer distribution of neutrons

See Chuck Horowitz's talk





Pb Radius Experiment (PREX)

Calcium Radius Experiment (CREX)

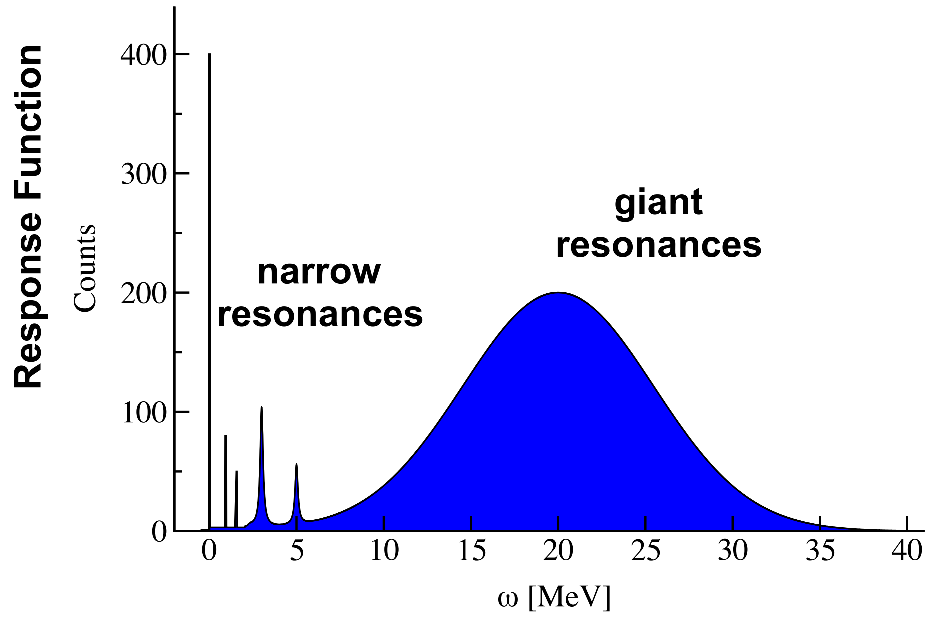
MREX

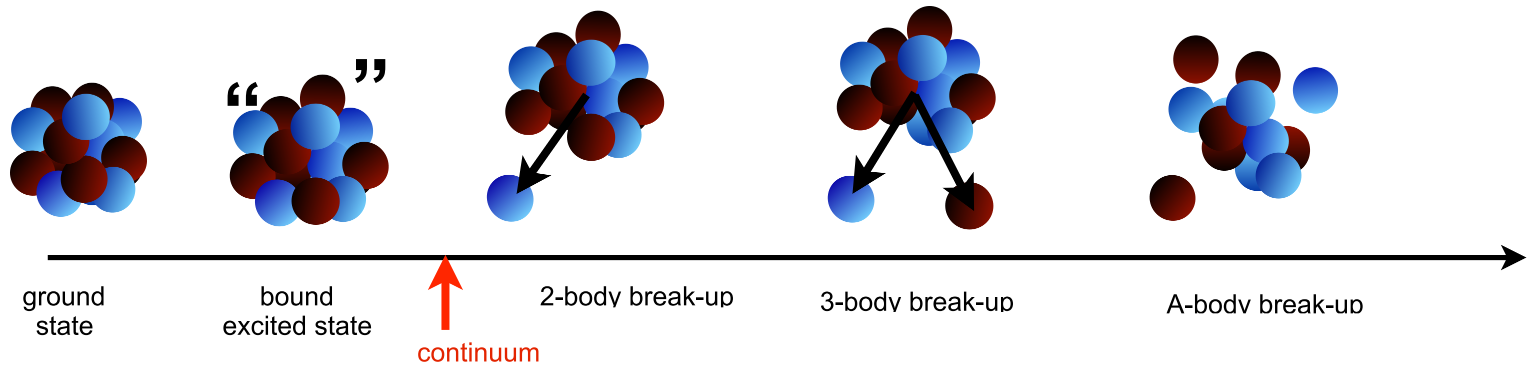
Mainz Radius Experiment (MREX)
At P2 experimental hall with ^{208}Pb

Outlook

What nuclear theory can offer

- Ab initio: look at ^{23}Na with deformed coupled-cluster, see PRC **102**(R) 051303 (2020).
- Study of nuclear effects in BSM processes, Hoferichter et al., PRD 102, 074018 (2020).
- Study of inelastic processes, Van Dessel et al. arXiv:2007.03658





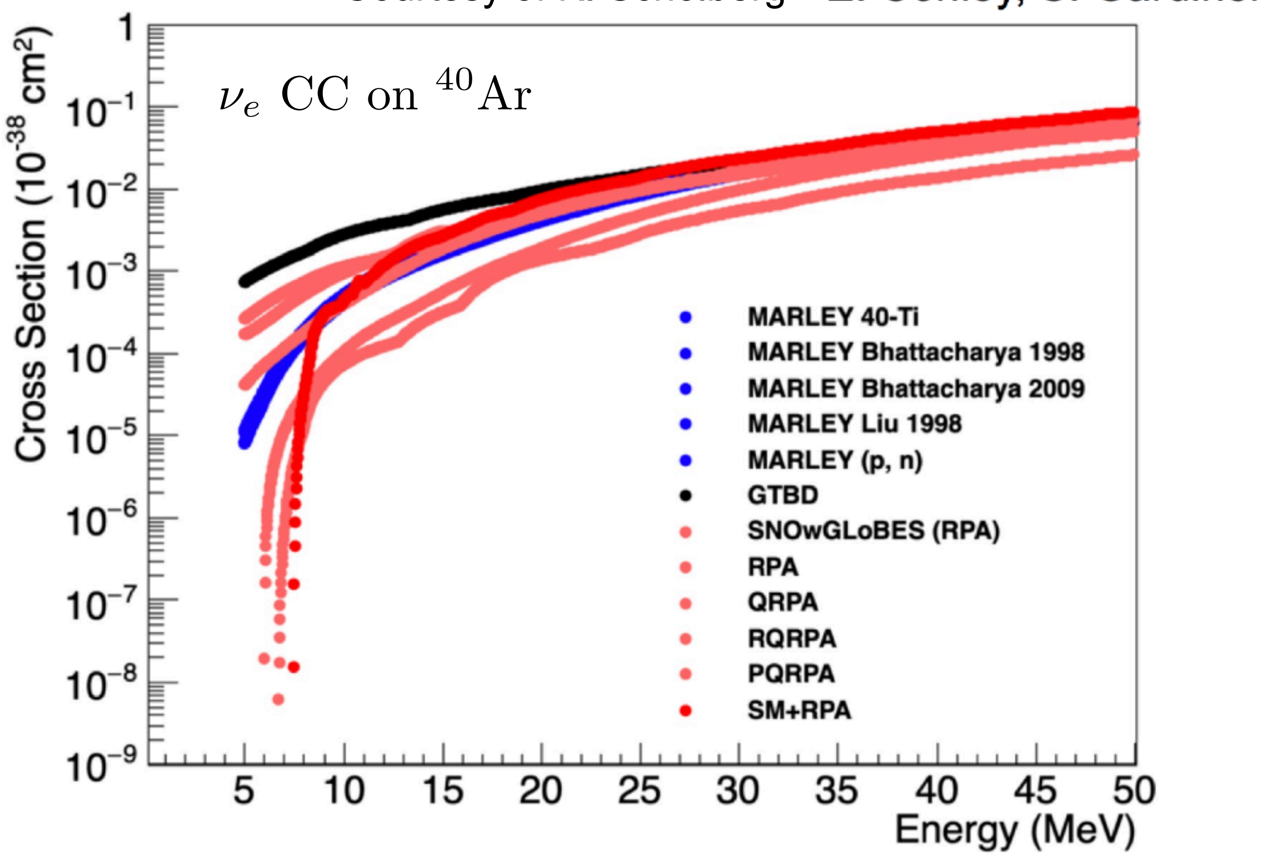
Outlook

What nuclear theory can offer

- Ab initio: look at ^{23}Na with deformed coupled-cluster, see PRC **102**(R) 051303 (2020).
- Study of nuclear effects in BSM processes, Hoferichter et al., PRD 102, 074018 (2020).
- Study of inelastic processes, Van Dessel et al. arXiv:2007.03658

My guess: uncertainties will be > 10% but still useful also for supernovae neutrinos

Courtesy of K. Scholberg E. Conley, S. Gardiner



Thanks for your attention!